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MANNED EVALUATION OF THE PROTOTYPE MK 12 SSDS, HELIUM-OXYGEN MO--ETC(U)
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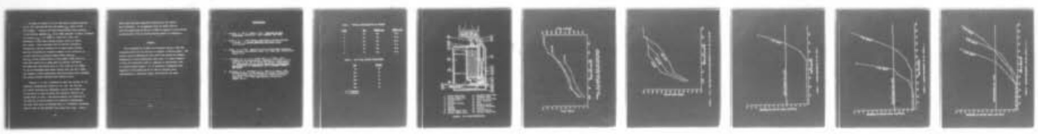

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NAVY EXPERIMENTAL DIVING UNIT

REPORT 10-77

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UNITED STATES NAVY

PANAMA CITY, FLORIDA 32407

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
PANAMA CITY, FLORIDA 32407

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September 1977

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ABSTRACT

The Prototype MK 12 SSDS, Helium-Oxygen System was evaluated to test the ability of the system to support a diver performing sustained heavy work, and to establish the life expectancy of the carbon dioxide absorbent bed. During graded exercise the divers' heart rate and helmet CO_2 levels were measured. During cannister studies, the cannister effluent was continuously monitored for CO_2. Analysis of the data revealed that the system can support a diver performing heavy work (3.0 L/Min O_2 consumption). However, the carbon dioxide absorbent bed was shown to have a life expectancy incompatible with operational dives at normal working depths.

INTRODUCTION

In 1976, the U.S. Navy Mark 12 Surface Supported Diving System (SSDS) successfully completed both technical and operational evaluations in the open circuit air mode. The system consists of thermal undergarments, dry suit, outer garment, neck ring, comfort plate, weights, rubber boots, helmet, and umbilical (gas supply, safety lines, and communications). Ongoing engineering on the Mark 12 has resulted in the development of a recirculator assembly for use in semi-closed mode with mixed gas. This assembly consists of a manifold, an ejector, an emergency gas bottle, associated valves and hoses, and a CO_2 absorbent bed contained in a 5.7 liter cannister (Figure 1).

During normal operations, surface supplied gas is delivered to the manifold of the MK 12 SSDS recirculator assembly. Here the gas is directed to the ejector which is positioned in such a way that a venturi action secondary to gas flow through a .028" diameter orifice entrains gas from the CO_2 absorbent bed, drawing additional helmet gas into the cannister, and sends scrubbed and supply gas back into the helmet. In this manner, a small ejector flow is designed to produce a system flow sufficient for adequate helmet ventilation and carbon dioxide absorption.

To confirm the functional capability of the Prototype MK 12 SSDS at its operational depth, a 380 FSW saturation dive was scheduled at NEDU. While this system is neither designed nor intended for use in a saturation system, this method was selected to allow controlled experiments of longer duration than would have been possible had surface supported dive profiles been utilized.

Several factors affect the ability of a diver to perform sustained work while diving the mixed gas MK 12 SSDS. The most important of these is the level of carbon dioxide (P_{CO_2}) inside the helmet. This value is dependent upon helmet ventilation rate, efficiency of the carbon dioxide absorbent bed, and the diver's rate of carbon dioxide production. The purpose of the study is twofold:

(1) to test the ability of the system to support a diver performing sustained heavy work, and

(2) to establish the life expectancy of the carbon dioxide absorbent bed.

METHODS

The sixteen day simulated dive was conducted in the Ocean Simulation Facility of the Navy Experimental Diving Unit. Six experienced, healthy male divers served as subjects. Physical characteristics of the men are depicted in Table 1. All subjects performed calisthenics and a run of up to 7 Km five days per week for eight weeks prior to the dive. In addition, each man performed ten to twelve underwater work cycles, similar to the experimental protocol, during the pre-dive period.

Each diver wore the Prototype MK 12 SSDS. Breathing gas was delivered to the manifold via 600 feet of MK 12 umbilical hose at overbottom pressures calculated to produce a system flow of 6 ACFM, previously reported by Thalmann (1974) to prevent helmet P_{CO_2} from exceeding the established Navy limit of 2% surface equivalent value (SEV) with a diver performing heavy work loads ($\dot{V}O_2 \cong 3.0$ liters/minute). The overbottom pressures used were 26 psig at 20 FSW, 45 psig at 200 FSW, 55 psig at 380 FSW, and 60 psig at 450 FSW. The actual system flows were not measured.

During baseline measurements at 20 FSW the breathing gas was 80% helium - 20% oxygen (P_{IO_2} of 244 mmHg), while at 200 FSW it was 92% helium - 8% oxygen (P_{IO_2} of 429 mmHg), and at 380 and 450 FSW it was 95% helium - 5% oxygen (P_{IO_2} of 476 and 556 mmHg respectively). The gas mixtures at depth

were selected to replace standard shipboard mixed gas (84% helium - 16% oxygen) to obviate oxygen buildup in the chamber complex which would have placed the divers at increased risk of suffering oxygen toxicity.

The experimental protocol was divided into two phases. The first phase consisted of graded exercise to evaluate the ability of the dive system to support a working diver. The initial portion of each graded exercise sequence was a ten minute rest period. This was followed by six-minute work periods, separated by four minutes of rest, at 25, 50, 75, 100, 125, and 150 watts on an especially modified pedal ergometer (James 1976) mounted on a frame approximately fifteen feet underwater. This sequence was carried out at 1.6 ATM (20 FSW), 12.52 ATM (380 FSW), and 14.64 ATM (450 FSW). Since the resistive fluid medium alone has been estimated to increase the work of cycling by 33 - 42% (Costill), it is possible that the actual work performed to overcome the combined resistance of the ergometer, water, and thermal suit may have increased the net work output to perhaps twice the indicated load.

All measurements were made during the final minute of each exercise period. Conventional ECG leads were fastened to fixed locations for measurment of heart rates. Gas samples were vented from the recirculator inlet and outlet through a 1/8" O.D. tube at an appropriate flow rate to a mass spectrometer located

outside the chamber. Throughout portions of the experimental sequence continuous recordings were obtained of heart rate, and the oxygen and carbon dioxide fractions of the gas passing into and out of the recirculator. Water temperature was maintained at 15.6°C.

The second phase of the experimental protocol was designed to evaluate the life expectancy of the carbon dioxide absorbent bed. It consisted of exercise periods identical to those used in phase one. However, the work load used was maintained at 75 watts, and the only parameter recorded was a continuous tracing of the carbon dioxide fraction in the gas passing out of the recirculator assembly. Exercise continued until "cannister breakthrough" was obtained, defined in this study as the point at which the CO_2 in the cannister effluent attained a value of 0.5% SEV. Baralyme was the CO_2 absorbent utilized.

RESULTS

Figure 2 shows the mean helmet P_{CO_2} levels for the six work rates at 20, 380, and 450 FSW. At no point during graded exercise did the helmet P_{CO_2} reach 2% SEV (15.2 mmHg), although it approached this value during the 150 watt load at 450 FSW. During each rest period between work cycles, the helmet P_{CO_2} decreased to less than 0.5% SEV. At rest there was no significant difference between the helmet P_{CO_2} at 20 FSW and that found at either 380 or 450 FSW. During graded exercise, however, there was a statisticallly significant difference ($p < .01$) between the mean helmet P_{CO_2} at 20 FSW and that found at both 380 and 450 FSW. There was no significant difference between the values observed at 380 and 450 FSW.

Figure 3 shows mean heart rate plotted against work load at 20, 380, and 450 FSW. The heart rate, which is directly proportional to oxygen consumption, increased in a linear fashion with increasing work loads at all depths. The plots obtained are similar, and the mean rates for the maximum work loads at 20, 380, and 450 FSW were 172, 174, and 180 respectively. If it is assumed that actual work output was 33% greater than that indicated on the ergometer, or if the above heart rates are correlated with values obtained during work in the dry laboratory at one atmosphere pressure, the estimated oxygen consumption at maximum tolerated work was approximately 3 liters per minute (Astrand, 1970).

Figures 4, 5, and 6 are graphic depictions of cannister effluent P_{CO_2} versus time in minutes at 20, 200, and 380 FSW. All curves shown are remarkably similar, and differ only at the point in time at which cannister effluent CO_2 levels begin to rise. As shown in Table 2 the mean cannister duration for all depths combined was 79 $\pm$ 13 minutes.

DISCUSSION

The amount of work man can perform in a dry environment usually is limited by the function of the cardiovascular system. In diving, however, ventilation often proves to be the primary limitation. If a diver's ability to increase ventilation with increasing ventilatory requirements is diminished, the level of carbon dioxide in the blood and tissues rises. As this occurs, a number of physiological responses occur, some of which can prove hazardous or even fatal to the diver. Among these are an increased susceptability to inert gas narcosis, decompression sickness, and oxygen toxicity, an increasing somnolence, possible coma, and convulsions. It is obvious, then, that ventilatory restrictions to diver work performance play a major role in the design criteria for any prospective underwater breathing apparatus.

Restrictions to adequate ventilation usually result from one of two factors. First, elevated breathing gas density increases the resistance to gas flow in the airways of the lungs and in the breathing apparatus. This can result in either an excessive work of breathing with a subsequent deterioration of useful work output, or a reduction in adequate ventilation accompanied by carbon dioxide retention. If the restriction is sufficiently severe, both a reduction in work output and carbon dioxide retention may occur. The second factor that may lead to inadequate ventilation is elevated carbon dioxide levels in the diver's breathing gas. In such a situation, a reduction in effective ventilation may occur and lead to carbon dioxide retention.

The Prototype MK 12 SSDS used in this study is a semi-closed helium-oxygen system. The use of helium-oxygen rather than air at the depths of this study obviated ventilatory restrictions due to increased gas density. The densities of the respired gas mixtures were .6 g/L at 20 FSW, 3.07 g/L at 380 FSW, and 2.11 g/L at 450 FSW. The use of a helmet in a recirculating mode with carbon dioxide absorption, however, can lead to increased ambient carbon dioxide with resultant carbon dioxide retention. Since helmet carbon dioxide levels are dependent upon CO_2 production, CO_2 absorption, and helmet ventilation, the purpose of this study was to ensure that the system would support a diver performing maximum work, and establish the life expectancy of the CO_2 absorbent bed.

As shown in Figure 2, at no time during graded exercise at 20, 380, and 450 FSW did the helmet P_{CO_2} reach 2% SEV (15.2 mmHg). Sinclair and Welch demonstrated that exercise in air with an ambient P_{CO_2} of 21 mmHg resulted in small increases in arterial P_{CO_2} (3.6 mmHg) at light work loads that decreased to near mean resting control levels at heavy work loads. They concluded that an ambient atmosphere containing a partial pressure of 21 mmHg carbon dioxide was well tolerated by subjects engaged in any activity up to and including strenuous steady state exercise. The CO_2 levels demonstrated in the present study were not only well below the 21 mmHg used by Sinclair and Welch, but they were also below the U.S. Navy limit of 15.2 mmHg. It can be concluded from these results that the MK 12 SSDS can support a diver performing continuous heavy work provided the carbon dioxide absorbing bed remains active.

Figures 4, 5, and 6 graphically show the results of the cannister breakthrough studies at 20, 200, and 380 FSW. All curves obtained are remarkably similar and differ only at the point in time at which the cannister effluent CO_2 levels begin to rise. The curves support the selection of .5% SEV CO_2 as the criterion for cannister breakthrough, for once this value is reached there is a markedly increasing rate of rise in the effluent CO_2 levels with time. Table 2

shows that the mean cannister duration for all depths was 79 minutes. It is apparent from the above results that the capability of the MK 12 SSDS to support a diver during an operational dive at maximum working depth is inadequate.

SUMMARY

The Prototype MK 12 SSDS was evaluated during a 380 FSW saturation dive for its ability to support a working diver. The results clearly demonstrate that while the system can support temporarily a diver performing heavy work, it cannot support a diver for sufficient time to complete an operational dive at normal working depths. It is therefore recommended that approval of the mixed gas MK 12 SSDS be delayed until improvements in cannister design and function are made.

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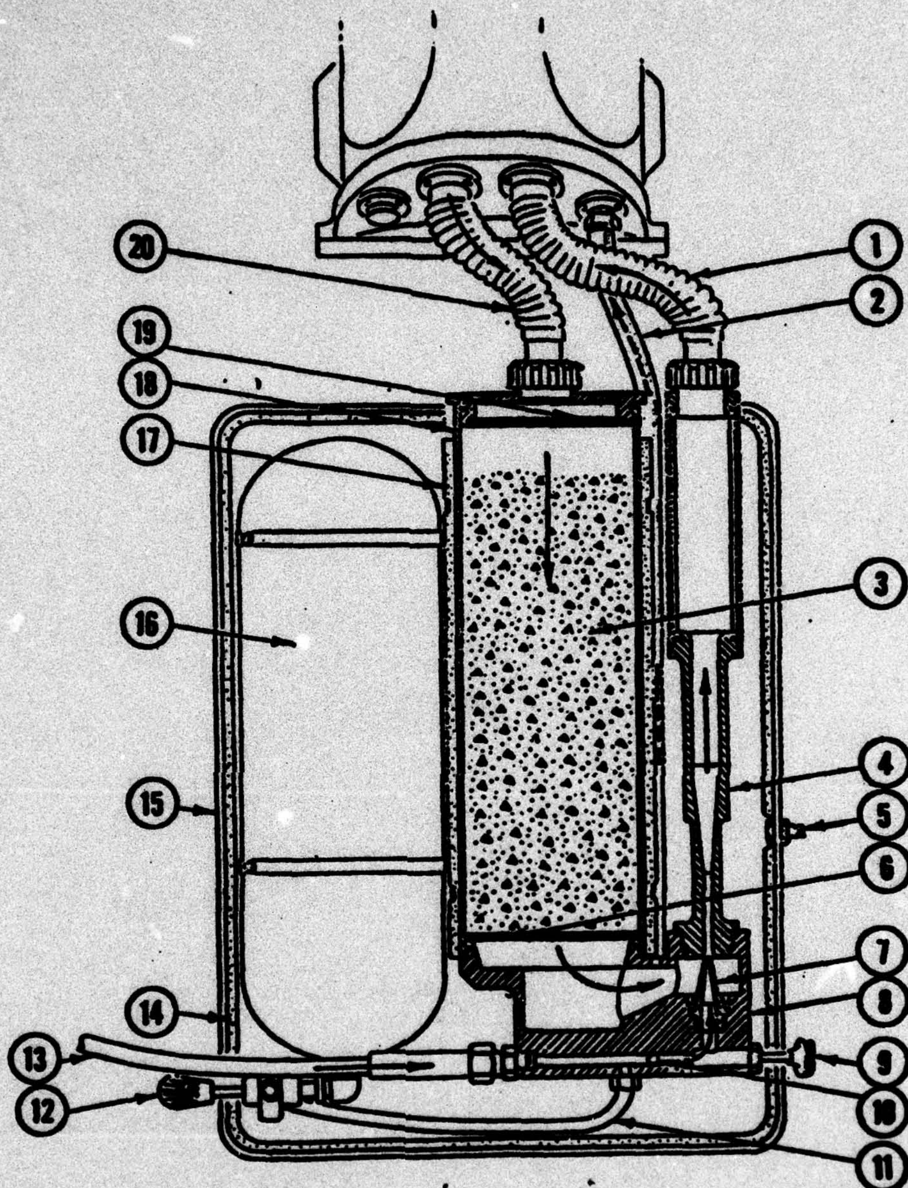
TABLE 1 PHYSICAL CHARACTERISTICS OF SUBJECTS

DIVER	AGE	HEIGHT (cm)	WEIGHT (kg)
1	35	180	79.8
2	34	178	77.6
3	36	183	92.1
4	28	175	67.1
5	32	183	93.9
6	27	168	76.2

TABLE 2 MK 12 SSDS CANISTER BREAKTHROUGH

FSW	MINUTES
20	70
200	92
200	61
380	73
380	87
380	90

$\bar{x}$ = 79 Minutes
σ = 13 Minutes



1. Helmet Supply Hose
2. Ejector Bypass Whip
3. Scrubbing Agent
4. Ejector
5. Hot Water Fitting
6. Screen
7. Ejector
8. Manifold
9. Ejector Supply Valve
10. Ejector Bypass Access
11. Emergency Supply Hose
12. Emergency Valve
13. Mixed Gas Supply Whip
14. Shell Insulation
15. Shell
16. Emergency Bottle
17. Canister Insulation
18. Canister
19. Screen Deflector
20. Canister Supply Hose

FIGURE 1. MK 12 SSDS RECIRCULATOR

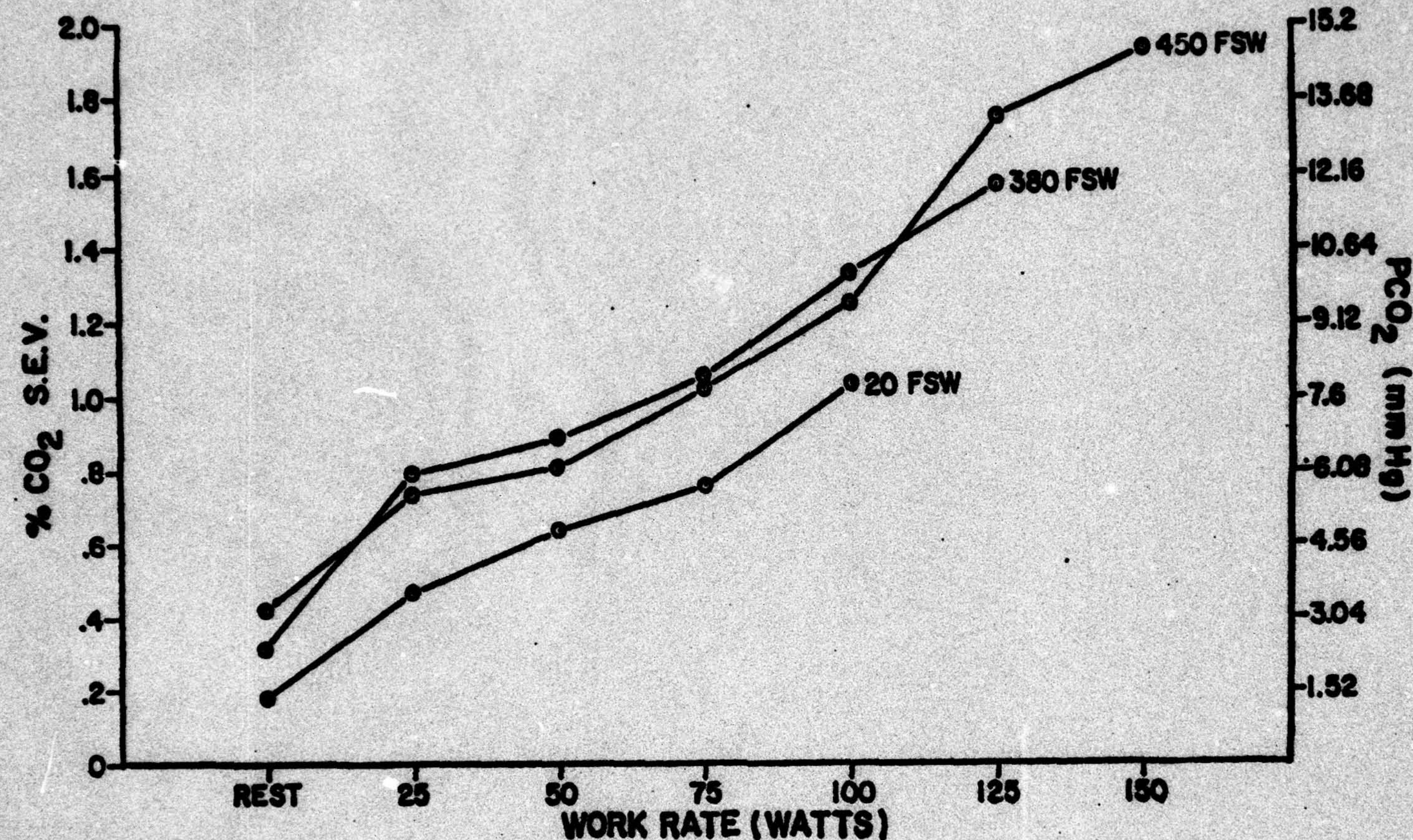


FIGURE 2. MK 12 HELMET CO_2 LEVELS WITH GRADED EXERCISE
MEAN VALUES FOR DIVERS COMPLETING EACH WORK CYCLE

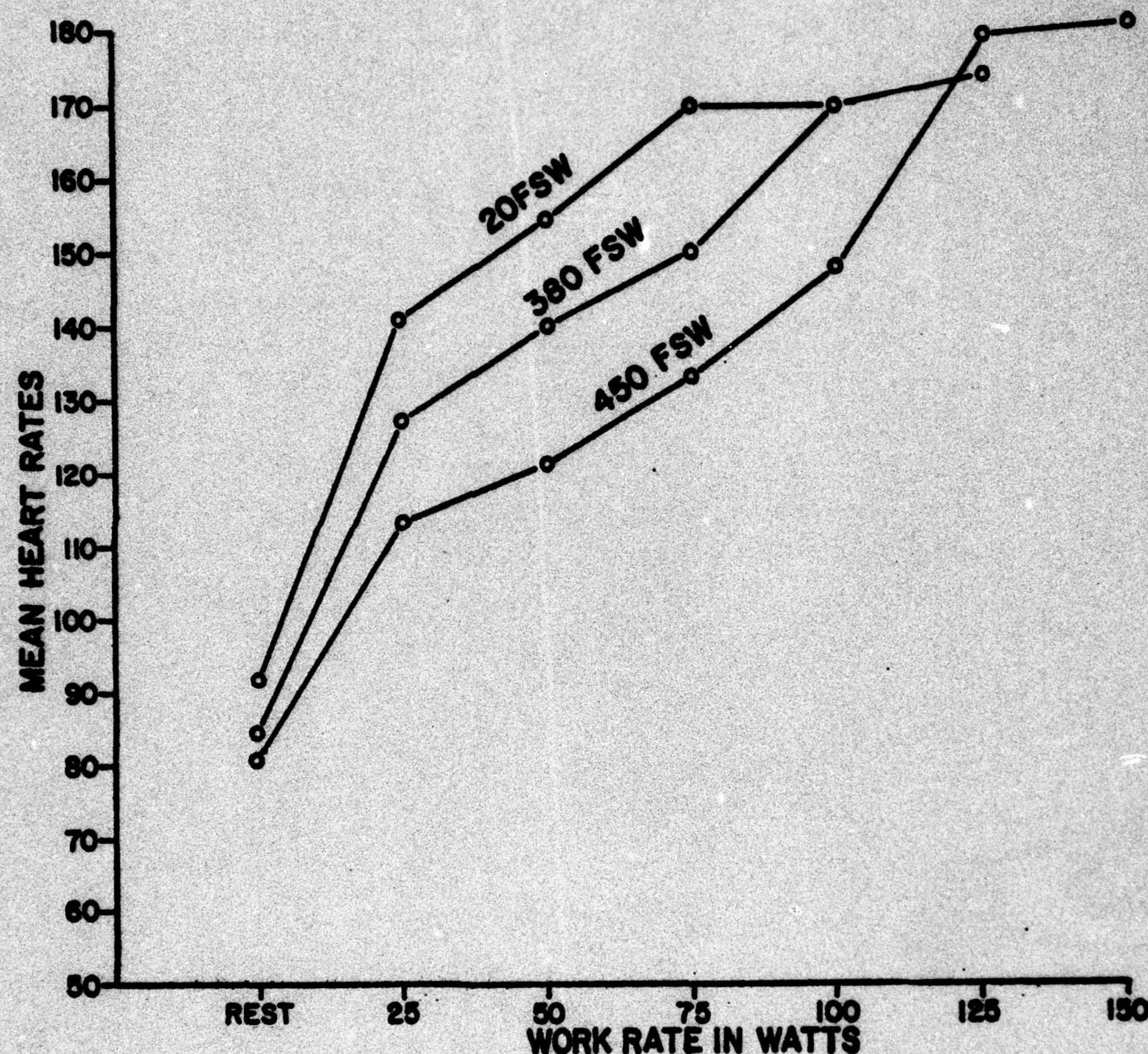


FIGURE 3. MK 12: MEAN HEART RATES WITH GRADED EXERCISE AT 20, 380, and 450 FSW

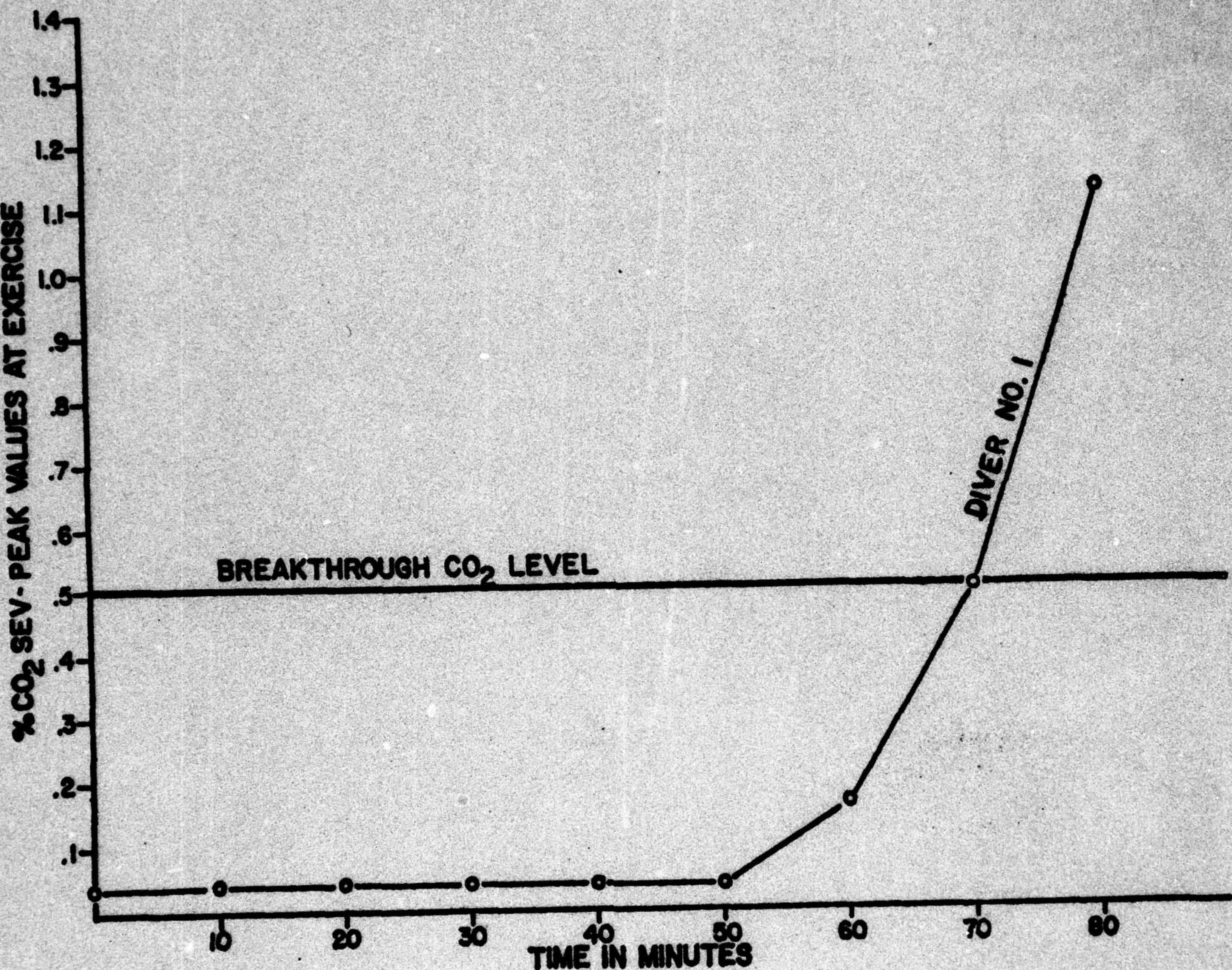


FIGURE 4. CANISTER BREAKTHROUGH, 20 FSW, DIVER 1

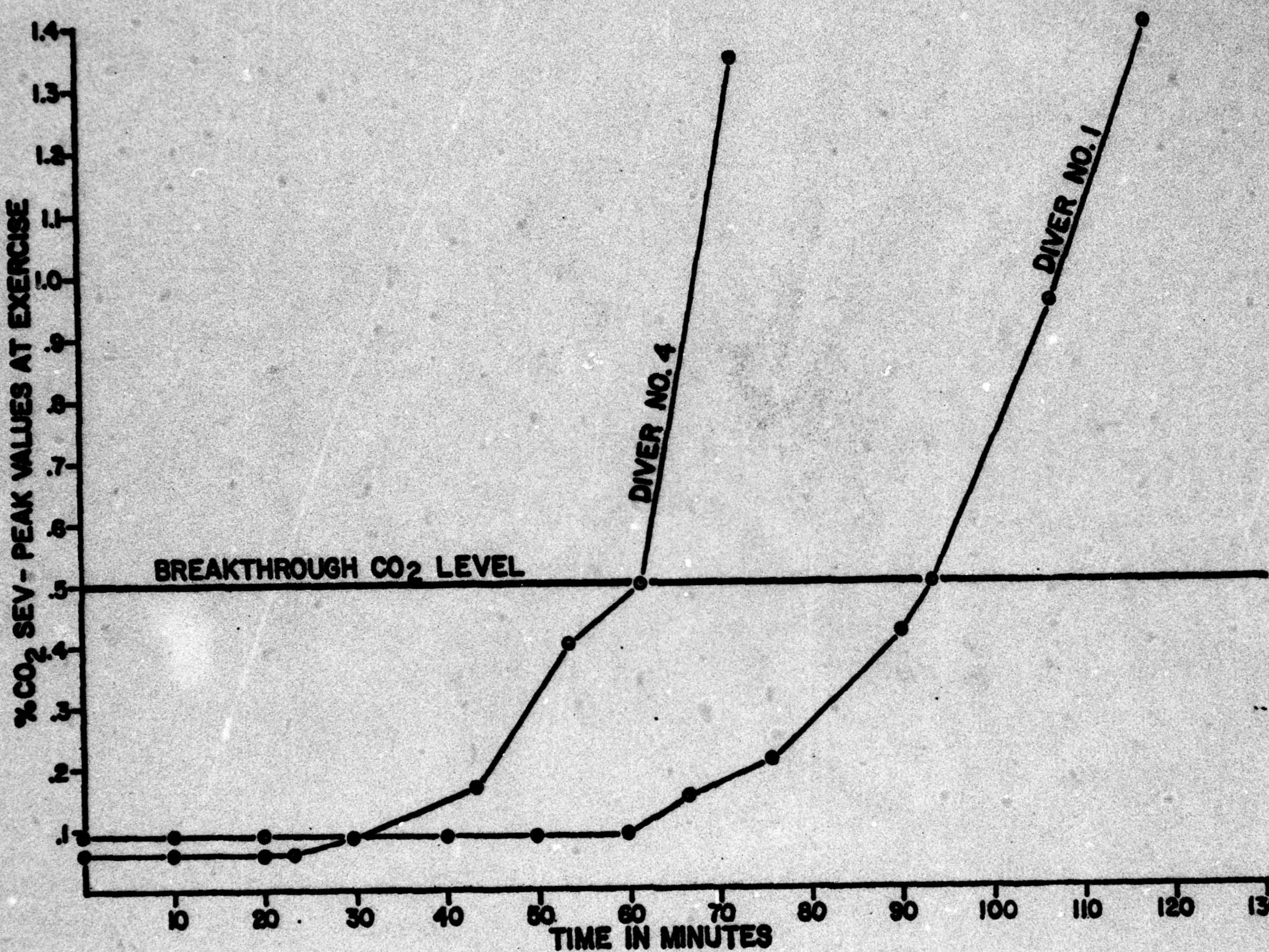


FIGURE 5. CANISTER BREAKTHROUGH, 200 FSW, DIVERS 1, 4

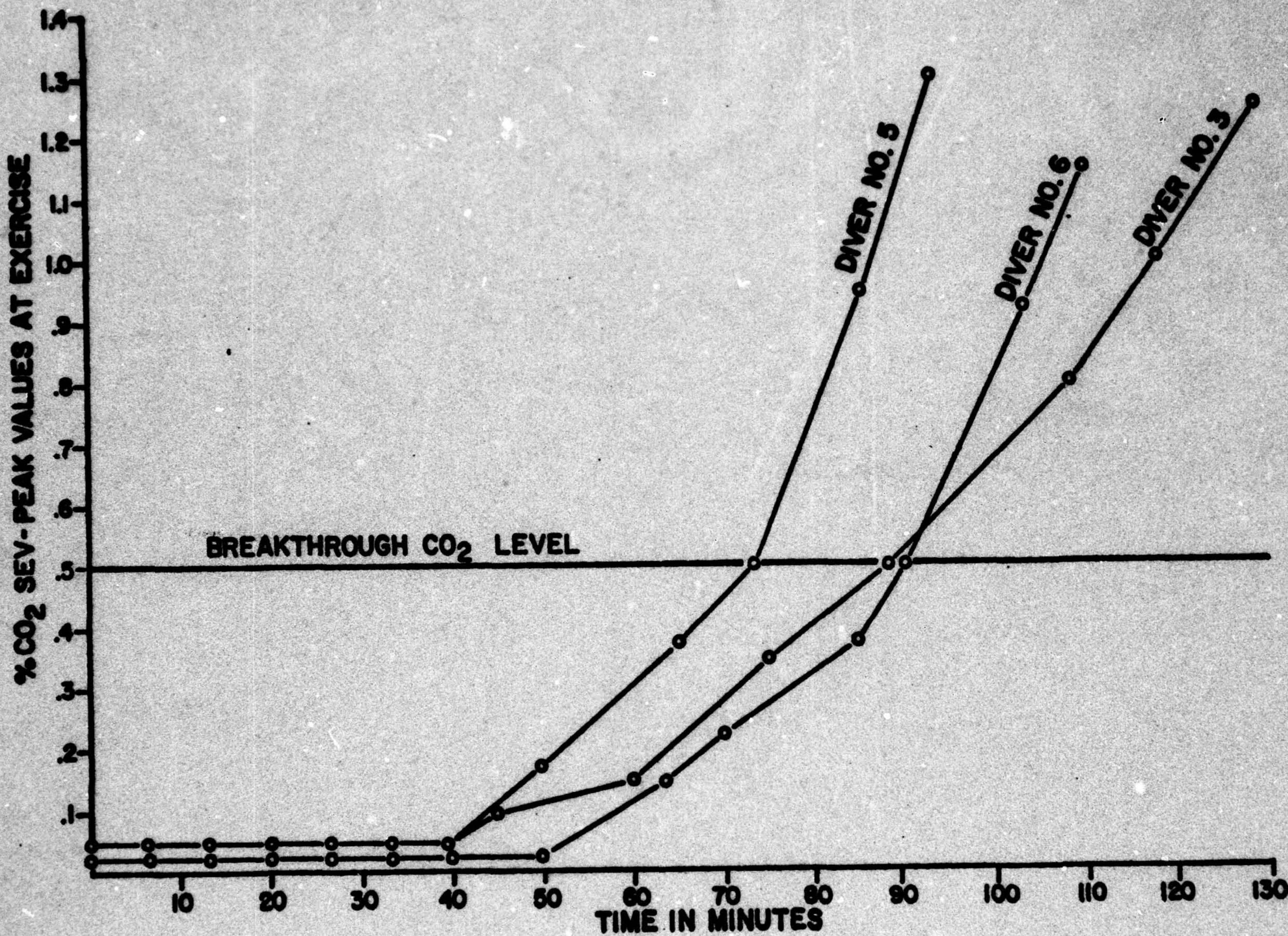


FIGURE 6 CANISTER BREAKTHROUGH, 380 FSW, DIVERS # 3, 5, 6